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STUDY OF WELDING FUME CHARACTERISTICS OF NICKEL-ALUMINUM-BRONZE GAS METAL ARC ELECTRODES

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STUDY OF WELDING FUME CHARACTERISTICS OF NICKEL-ALUMINUM-BRONZE GAS METAL ARC ELECTRODES

1.0 Introduction

Complementary to an earlier study on welding fume characteristics (1) this report investigates the particulate fume emissions from two nickel-aluminum-bronze gas metal arc electrodes. These two electrodes warranted evaluation as their different chemistry suggested they would generate considerably different fumes from the two Cu-Ni electrodes studied earlier.

The composition and amount of fumes these electrodes generate will primarily determine their potential for producing excessively high concentrations. Such concentrations may have adverse effects on the health of welders and therefore investigation of their fume characteristics provides a basis for estimating the degree of pollution control which must be achieved in a welding environment.

This report gives an account of experiments to determine fume generation rates and fume compositions for Ni-Al-bronze electrodes. It also examines a technique for reducing the fume levels through ventilation.

2.0 Background

The general mechanics of fume formation and the factors affecting its production are detailed in the first report (2) on gas metal arc cupro-nickel electrodes.

Despite the fact that gas metal arc electrodes produce comparatively few fumes and make for cleaner welding environments, potential health hazards may result from using Cu or Ni type wires. The chemistry of Cu-Ni and Ni-Al-bronze electrodes is such that significantly high exposure to Cu and Ni fumes may occur. Furthermore, as the Threshold Limit Values* for Cu and

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*Threshold Limit Values are laid down by the American Conference of Governmental Industrial Hygienists. TLVs specify the maximum allowable concentrations of airborne contaminants to which a welder may safely be exposed to over normal working periods. These values are based on the best available information and subject to periodic review. In Canada compliance with TLV levels in industrial environments is advocated under standard CSA W117.2 (3).

Ni are low, a potential for excessive exposure does exist. Hence, there is good justification for understanding the actual characteristics of the fumes.

Many characteristics of welding fumes collectively determine their potentially detrimental effect on the welder's health (4). Two significant factors are the fume emission rate and the fume chemistry. Both the amount and composition of fumes emitted by electrodes play a key role in assessing the potential for excessive exposure to welding personnel. These two characteristics must be jointly assessed when evaluating the possibility of generating airborne concentrations in excess of established guidelines. Where electrodes emit highly toxic fumes, welders can safely tolerate exposure to only small amounts. Where the fumes are less toxic greater amounts can be tolerated. This is the philosophy embodied in the ACGIH handbook entitled Threshold Limit Values for Chemical Substances in Workroom Air. For example Cu and Ni fumes are considered to be more toxic than mild steel fumes so the accumulation of Cu and Ni bearing fumes in the welding environment must be controlled more stringently. Potentially hazardous fume concentrations resulting from Cu-Ni electrodes such as Ni-Al-bronze wires must be maintained at acceptably low levels for the benefit of personnel in the workplace.

2.1 Experimental Details

Welding conditions for two electrodes set out in Table 1 were extracted from procedures supplied by Physical Metallurgy Research Laboratories. As previously indicated, particulate fumes evolved by two gas metal arc electrodes were analyzed. Ampcotrode 10 and Ampcotrode 46 wires 1.6 mm in diameter were tested for their fume producing tendencies. These electrodes were obtained from Ampco Metal of Milwaukee and conform to AWS ER Cu Al-A2 specification. The chemistry of each wire is included in Table 2. Baseplates were supplied by the Physical Metallurgy Research Laboratories and were made of a Ni-Al-bronze alloy taken from heat #2347.

A chamber was used for all welding experiments to determine the rate at which fumes were generated by the electrodes. The large closed chamber with tapered hood culminating in an overhead exhaust orifice is depicted in Figures 1 and 2. Upward ambient air flow within the chamber was achieved by an in-line Roots vacuum pump model 2506 capable of drawing 324 m^3/hr of air from the chamber at a static pressure drop of 50 mm mercury.

Particulate emissions were collected at the top of the chamber by 25 cm x 20 cm Owens-Corning PF105 filters clamped over the orifice. However, samples for chemical analysis were gathered on small 25 mm Teflon LS filters manufactured by Millipore. These filters were inserted into the flexible probe of a portable constant flow Dupont sampler model P2500. All fume samples were weighed on a Mettler 150 electronic balance. In the final experimental work, a Tykron Phase IV commercial fume extractor was evaluated for fume control using a gun mounted nozzle. The nozzle was a stainless steel tube of 41 mm diameter and 3 mm wall thickness.

Welding of test consumables to produce fumes was performed within the same large steel chamber. The automatic welding system consisted of the following components; a Miller DC Deltaweld 450 constant potential power source, a stationary Miller GA50 gun and a carriage-mounted plate fixture.

2.2 Test Program and Measurement Procedure

(a) Calibration Test

To evaluate the accuracy of the experimental procedure for collecting electrode fumes the calibration test set out in AWS F1.2-79 was performed (5). The test employs an E70S-3 1.2 mm electrode run at a feedspeed of 7600 mm/min (approximately 225 A) on reverse polarity using a constant potential power source. A 19 mm electrical extension and 10° lagging torch angle are specified with a CO_2 shielding gas flow rate of 19 litres/min using a 19 mm diameter nozzle.

The above AWS procedure specifies both a wire feedspeed and suggested current at a given arc voltage. In the Welding Institute of Canada Laboratories wire feedspeed was accurately measured by tachometer. The transformer-mounted ammeter and voltmeter were visually checked against shunt measurements and seemed to be in close agreement.

The test was run at both 26 and 24 arc volts. Several fume generation rates were measured at each voltage and compared with the recommended AWS value (6).

To evaluate moisture absorption by filters during the calibration a 'dry-run' test was performed. A filter was pre-weighed, clamped into position within the chamber and the Roots blower turned on. After 90 seconds it was taken out and weighed again. The weight of moisture absorbed during the test was the difference between the two recorded filter weights. That moisture weight indicated a degree of variation introduced into calibration tests for electrode fume evolution.

b) Fume Generation Rate Measurement

Bead-on-plate welds were performed within the chamber for each experimental welding condition and the fumes evolved were collected and weighed.

Several preparations for each test weld were made. A 20 cm x 25 cm Owens-Corning fiberglass mat filter was weighed and then clamped into position over the orifice. The Ni-Al-bronze baseplate was secured in position. Space limitations within the chamber necessitated that the baseplate be inclined at about a 60° angle to the horizontal. A poor bead shape often resulted but there was no discernible effect on the experimental results.

As welding began the Roots vacuum pump was simultaneously activated to draw fumes vertically up into the filter. After completion of welding which took 30 seconds the vacuum pump was left running long enough to collect residual fumes. Subsequent weighing of the fume-laden filter permitted calculation of the fume generation rate in (FGR) g/min. The FGR was calculated by dividing the measured fume weight by the welding time.

Each fume test was replicated three times to establish a representative average value and also increase the confidence that could be placed in the experimental results. To enhance the accuracy of test results the following precautions were taken:

1. Plate surfaces were machined before each weld to remove potential fume contaminants.
2. Experiments were performed in a partially randomized order to minimize the introduction of time-dependent errors.
3. Prior to usage, filters were maintained in a dust-free plastic envelope.

The appearance of a typical filter is shown in Figure 3. The marked colour contrast around the outer perimeter suggests that a satisfactory seal was obtained between the clamping fixture and the filter. Also the small depth of discoloration signifies good particle retention properties.

(c) Samples for Chemical Analysis

Bead-on-plate welds were performed using each of the two electrodes. Fumes emitted by each wire were collected using sampling equipment of a type suitable for industrial hygiene monitoring.

Prior to welding, a 25 mm Millipore filter was installed in the fume probe of the Dupont vacuum pump. Welding was commenced without activating the Roots vacuum pump to permit fume concentrations to build up within the chamber. After welding, the probe was left suspended in the chamber until a visible deposit appeared on the Millipore filter. This fume deposit was forwarded to Concord Scientific Corporation for chemical analysis by optical emission spectroscopy.

Applicable procedures described in Section 2.2(a) to minimize experimental variation were again followed. In addition, moisture aborption which can lead to high variability of results, was minimized by using Teflon filters. Moisture absorption can introduce greater errors in this part of the work because the amount of fume collected is very small.

(d) Fume Control Tests

Several tests were performed to evaluate a gun-mounted local fume extraction unit using a Tykron Phase IV system (7) to provide an extraction rate of about 100 cfm. The special tube-nozzle assembly was positioned coaxially around the gun as depicted in Figures 4 to 7. The gun-mounted nozzle assured consistent positioning of the intake above the fume source at all times. The technique has distinct advantages in semi-automatic applications because the welder need not re-position an exhaust duct as he is welding.

However for optimum performance a suitable airflow condition had to be achieved. A high airflow velocity at the nozzle intake would promote excellent fume collection efficiency but would also draw away the protective shielding gas cover from the arc. Alternatively a low airflow velocity would not disturb the shielding gas but would provide very inefficient fume extraction. Hence some intermediate flow condition was called for.

In order to accommodate the shielding gas and maximize the quantity of fumes collected several nozzle improvisations were investigated. These ranged from drilling holes around the tube circumference to attaching a funnel shaped collector to the intake port. The different nozzle adaptations are illustrated in Figures 4 to 7 and the following list gives the sequence of tests performed.

1. Nozzle mounted about 3 mm from the tip of the welding torch.
2. Nozzle mounted 32 mm from welding torch tip and eight 4.5 mm diameter holes drilled around circumference of nozzle.
3. Same as 2) except 4 holes were closed.
4. Same as 2) except for the addition of a 5 mm collar attached around the nozzle circumference.
5. Funnel attached to nozzle with the funnel intake located so it was 45 mm from the plate during welding.

Evaluation of the nozzle extraction efficiency required that both the Tykron extractor and the Roots vacuum system were activated during a test weld. In this way, the fumes that were not captured by the gun-mounted extractor

would be collected on a pre-weighed filter at the top of the fume chamber. This filter was then weighed to determine the amount of fume collected and this value was compared to the fume weights obtained under identical welding conditions but without operating the gun-mounted extractor. Thus the collection efficiency of the gun-mounted extractor could be determined by the following calculation:

$$E = [(W_2 - W_1)/W_2] \times 100\%$$

E = collection efficiency of gun mounted nozzle.
W_1= weight of fume collected in t seconds with both Roots vacuum system and the Tykron extractor operating.
W_2= weight of fume collected in t seconds with only Roots vacuum system operating.

3.0 Experimental Results

3.1 Calibration Test

The calibration test to assess the accuracy of the procedure for measuring electrode fume formation was run at 26 and 24 arc volts. Several fume generation rates were measured at each arc voltage and compared with the AWS values (8).

The experimental results are listed in Table 3. At 26 arc volts the test was performed initially three times and fume generation rates in excess of the allowable AWS values resulted. The arc voltage calibration and contact tip-to-work distance were then checked and re-adjusted as recommended (9). The test was then run twice and electrode fume generation rates conformed to the AWS permissible range of value (0.530 g/min $\pm$ 10%). At 24 arc volts three preliminary tests again produced electrode fuming rates exceeding the AWS allowables. The same corrective adjustments as before were undertaken. The test was then run four times. All four results fell within the allowable range of electrode fume generation rates (0.43 g/min $\pm$ 10%).

It was felt that the filter might pick up moisture during the calibration tests. The additional filter weight would contribute to apparently excessive electrode fuming rates recorded during the preliminary tests at each arc voltage. To verify the hypothesis two 'dry-run' tests for moisture absorption were conducted. These showed the filter to gain on average 0.0484 g during the 90 second test. That translated into 0.032 g/min moisture pickup by the filter or a maximum 7% of any fume generation rate recorded in Table 3. By subtracting this moisture weight from the filter weight before calculating electrode fume generation rate, higher-than-average results in Table 3 would be lowered to more acceptable levels.

Hence the calibration tests ideally produced fume generation rates within ± 10% accuracy as recommended by the AWS. This variation was exceeded in the Cu electrode experiments due to inevitable deviations from calibration test conditions.

3.2 Ampcotrode 10 Electrode

Fume generation rates observed with the Ampcotrode 10 wire over a range of welding parameter settings are listed in Tables 4 and 5. Low current-voltage conditions produced small amounts of fumes whereas high current-voltage conditions produced more fumes. Therefore current and/or voltage variations did modify fume generation rates.

As currents were increased greater amounts of fume were produced (Figures 8-11). The trend was most pronounced with helium rich shielding in which a 300% increase in fume generation from the low to high current range (Figure 10) was observed. On the other hand the argon rich mixture resulted in only a 50% increase (Figure 8).

Maximum fume evolution from this electrode was 0.6 g/min at 330A obtained with 50% helium shielding (Figure 10). The minimum fume evolution was only 0.2 g/min at 270A observed for all test conditions with the Ampcotrode 10. Fume generation rates for the Ampcotrode 46 electrode remained largely between the same upper and lower values observed for the Ampcotrode 10.

However the Cu-Ni electrodes of the first report for the most part displayed 20-30% higher maximum fume generation rates (10).

The effect of increasing voltage on the fume generation of Ampcotrode 10 is depicted in Figures 12 and 13. When switching from 27 volts to 29 volts the quantity of fumes evolved remained essentially unchanged with two exceptions. Figure 12 suggests that at 300A the fume generation increased appreciably when switching from 27 to 29 volts. Figure 13 on the other hand suggests that at 330A the fume generation decreased markedly over the same voltage range. Comparable tests for the Ampcotrode 46 wire yielded similar results with voltage variations generally having negligible effect on the amount of fume generated. By contrast the Cu-Ni electrodes of the first report showed voltage increases producing increases in fume generation under certain conditions (11).

In summary, the Ampcotrode 10 electrode evolved greater fumes when run at higher currents. Voltage variations generally produced no change in fume generations, and the helium rich shielding produced greater fume evolution than did the argon rich mixture. Only this latter trend was uniformly evident in other electrodes investigated.

3.3 Ampcotrode 46 Electrode

Fume generation rates measured with the Ampcotrode 46 wire over a range of welding parameter settings are listed in Tables 6 and 7. The data is shown in Figures 14 to 19 to demonstrate the effect of arc voltage, welding current and gas mixture on the amount of fumes evolved.

Varying the welding current caused little variation in the quantity of fumes produced with argon rich shielding (Figures 14, 15). However, any meaningful trend could have been obscured by a 30% variation observed in replicated test conditions. These results were consistent with the findings from the first study.

Welding current variations clearly influenced the amount of fumes generated

where helium rich shielding was employed. The fume emissions observed at 27 volts rose from low currents to peak at 300A and then declined. The fume generation rate curve thereby acquired a characteristic peaking shape. The electrodes investigated in the first study tended to display a similar pattern. Therefore, the highest current settings did not produce the greatest fume emissions. The maximum fume emission observed was again 0.6 g/min at 300A but only 0.4 g/min at 330A (Figure 16). The effect was not as pronounced for 29 volts (Figure 17).

Varying the voltage generally produced no appreciable change in the amount of fumes emitted (Figures 18 and 19). The Ampcotrode 46 displayed two exceptions to this generalization (Figure 19). Switching the voltage from 27 to 29 volts at 300A diminished fume production but at 330A increased it. The Ampcotrode 10 wire behaved similarly but neither electrode investigated in the first study produced such a null correlation between arc voltage and fume generation rate.

3.4 Chemical Analysis of Welding Fumes

The results for chemical analysis of fumes are displayed in Table 8. The fume samples were analyzed only for Cu and Ni as the levels of those toxic chemicals would likely determine permissible total fume concentrations in the absence of ozone formation.

The low Ni fume levels recorded reflected the low Ni chemistry of the two electrodes (Table 2). The Ampcotrode 10 evolved fumes containing from 0.037% to 0.42% Ni in helium rich shielding. The Ampcotrode 46 containing higher Ni content emitted fume of 1.08% Ni. Both electrodes investigated in the first report had six times higher Ni chemistries than the Ampcotrode 46 and hence generated enriched 8% - 13% Ni fumes.

Reproducibility of Ni fume chemistry was diminished by small sample sizes. The minute Ni components of the Ampcotrode 10 fumes promoted large variations. In lean helium shielding at 300A and 27 volts two repeated tests produced 0.036% and 0.015% Ni fume contents - a 140% variation. However the

Ampcotrode 46 evolved greater Ni fumes and results varied from 0.786% to 1.09% Ni content. The variation with these larger Ni samples was only 38%.

The Cu fume components were exceedingly large compared with the Ni. So percentage variation among replicated test results was generally reduced. Even so the replicated experiments revealed substantial variation among Cu fume levels. The Ampcotrode 10 in lean helium shielding at 300A produced 56% and 70% Cu fume chemistry in two successive tests. In helium rich shielding the corresponding tests showed 73% and 83% Cu in the fumes.

Variations in other repeated tests were such that additional Cu fume production trends could not be confirmed. The Ampcotrode 46 operating in helium lean shielding at 300A evolved fumes of 69% and 88% Cu in two sequential tests. In helium rich shielding the same electrode emitted fumes containing 76% and 88% Cu. Thus no trend could be ascertained. Neither the Cuprotrode 521 nor the Monel 451 provided any correlation between shielding gas and Cu fume production. Further experiments would be required to establish Cu fume emission trends for these electrodes.

In summary, the Ampcotrode 46 recorded no apparent change in fume emission when the current was increased in an argon rich shielding. In helium rich shielding however, a peak fume generation curve emerged. In most cases varying the arc voltage did not affect the fume generation rate. As reported in Section 3.2 helium shielding promoted higher fume generation rates in all tests.

3.5 Local Fume Extraction Tests

The results of these tests are given in Table 9, and it can be seen that through varying the geometry of the coaxially mounted tube a wide range of fume control efficiencies were attained. Initially, the extraction nozzle was located too close to the arc and consequent disturbance of the shielding gas was evident by virtue of the fact that acceptable welds could not be achieved. As a result it was noted that the fume generation rates were higher than previously recorded. This was due to the removal of the shield-

ing gas and the resultant availability of ambient air within the arc region. Greater oxidation of fume particles resulted which was measured as increased fume generation. The problem was solved by retracting the tube nozzle further up the gun to reduce the vacuum suction at the arc. The shielding integrity was thereby maintained. Next a funnel-shaped collector was attached to the tube intake and no improvement in fume exhaust efficiency was recorded.

The tube nozzle extracted fumes more effectively with the funnel removed and a ring of eight small holes drilled just above the tube intake (Figure 4). The unit thereby achieved 16.8% efficiency. It was felt that fewer holes could improve the efficiency. Therefore, four holes were employed with a resultant 32.5% fume capture efficiency. To further restrict the clean air from approaching the eight holes a blocking collar was secured concentrically over the tube just above the ring of small ports (Figure 5). That nozzle configuration achieved 35.6% fume extraction efficiency which was the most successful experimental result. Higher efficiencies could possibly have been achieved. However, time constraints prevented extensive experimental trials to determine the absolute optimum geometric configuration for the gun extractor assembly.

4.0 Discussion

The results of calibration tests for electrode fume formation show that with sufficiently accurate parameter settings test results adequately conformed to the AWS suggested values. The AWS recommendation allows a $\pm$ 10% variation from these values to accommodate inevitable minor variations in the test set-up. Several factors contributed to this variation.

In the first place test currents varied from one calibration experiment to another by as much as 20%. As current is a dominant factor in determining electrode fume generation rates (12) some variations in FGR would be introduced. On the other hand the AWS procedure (13) gives 225A only as approximate so the various currents listed in Table 3 would meet this guideline. Some current variation would be accommodated within the $\pm$ 10% permissible tolerances on electrode fuming rate.

A further source of variation during these calibration tests stems from moisture absorption by the filter. It was calculated to be 7% maximum but 5 - 6% on average. By subtracting this moisture weight from the fume weights in Table 3, higher than average electrode fume rates would be adjusted downwards to approach the AWS recommendation. However, the calibration tests were performed over several days which could reduce accuracy because of atmospheric humidity changes. Interestingly, an AWS study (14) found that the humidity level in the welding area did not significantly affect fume concentration measurements with E70S-3 wires but did with E70T-4 wires. That study merely sampled fume levels whereas the present experiments measured total fume evolution using different filters and test techniques. Also the AWS study was conducted without controls so additional controlled experiments should be performed to verify the AWS conclusions.

The electrodes investigated displayed recognizable trends in fume generation characteristics despite marked variation in certain replicated test results. Fluctuating oxide formations, atmospheric humidity changes and tolerances on parameter settings would account for variations in experimental readings. On the other hand, the combined average $\pm$ 8% variation from mean values demonstrated a measure of conformity with the AWS $\pm$ 10% calibration recommendation. Furthermore variation of welding parameters, shielding gas and electrode chemistries did establish some visible fume production trends. Comparison of the hygienic benefits of the two electrodes was thereby rendered possible.

The different chemistries of the two wires investigated would logically promote different fume production tendencies. Hence, three different fume generation-versus-current curves were observed. A constant fume generation typified the first, a constant increase in fume generation the second and a peaking curve the last.

The constant fume generation curve independent of current was inconsistent with established theory which maintains that current does influence fume generation (15). As already pointed out the significant variation in replicated conditions could have obscured this trend.

The peaking fume generation curve was peculiar to the Ampcotrode 46 which was maximum at 300A and to a lesser extent the two electrodes studied in Part I. Had these curves been extrapolated the correlation would move towards increasing fume generation with increasing currents. The dip following the peak would hence be a localized phenomenom (16). Heile and Hill postulate that a transition phase in the mode of metal droplet transfer across the arc could explain such a dip (17). Further experiments could be undertaken at higher currents to chart the dip or minimum fume evolution condition. By selecting such an operating point welding could be optimized from a hygienic viewpoint. No such dip was apparent in the monotonically increasing fume generation of the Ampcotrode 10.

Varying arc voltages for the most part produced only marginal increases and decreases in the fume generation rates of either electrode. However as only two voltage settings were employed additional experiments over a broader range should be performed for verification. This trend is inconsistent with recorded experience. Fume generation rates increased with arc voltages for all electrodes investigated in a recent AWS research project (18). That trend was partially consistent with electrode performance as documented in the first report (19).

Helium rich shielding produced increased fume evolution over argon for all electrodes tested including those of the first report. The Ampcotrode 46 recorded a 100 percent greater fume generation in helium than argon rich shielding for the worst fuming condition but most comparisons were much less extreme. There may be several explanations for the increased fume producing tendency of helium shielding. Helium runs hotter than argon (20) and thus enhanced vaporization of fumes could be anticipated. In addition helium is a light low density gas which could promote shielding turbulence with resulting aspiration of air into the arc zone. Oxidation of fume particles would then increase the apparent fume generation as observed in these tests.

Chemical analysis of fume samples varied between identical experiments due to minute sample weights. This promoted appreciable percentage deviations. A small Teflon filter registered up to 0.2 g Cu and 0.5 g Ni in a 'dry-run'

test. As the filter was dissolved during analysis a measure of variation was introduced. Water vapour condensation on the filter compounded the variation. Changes in oxide formation due to natural process fluctuations further restricted exact replication of test results. Even so Cu fume content variations over repeated experiments averaged only + 15%.

Fume control requirements may be established from the total amount of fume generated together with the amount of the most toxic ingredient determined here as Cu. Whichever concentration exceeds its upper limit first becomes the critical indicator of acceptable fume levels. The acceptable Cu concentration is 0.2 mg/m^3 and the acceptable total fume concentration is 5 mg/m^3 (21). Thus a Cu fume generation rate greater than 4% of the total would be critical. The Cu content of both electrode fumes investigated greatly exceeded 4%. Therefore a Cu concentration of 0.2 mg/m^3 would be achieved long before the total fume concentration reached 5 mg/m^3.

One may calculate how much welding time is required to achieve this critical 0.2 mg/m^3 Cu fume concentration throughout the working environment assuming no ventilation. Consider a welding area 10 m x 10 m x 10 m. Assuming uniform fume density this room would accept up to 200 mg of Cu before the Cu fume level reached 0.2 mg/m^3. Suppose the electrode emitted fumes at 0.5 g/min with 40% Cu content. Copper would be evolved at 0.2 g/min or 200 mg/min. Therefore welding for one minute would achieve the critical Cu concentration in the welding environment. Based on the foregoing example a tabulated comparison of four electrodes is presented below.

Allowable Welding Time to Reach Critical Cu Fume Concentration of 0.2 mg/m^3 Based on a 10 m x 10 m x 10 m Room.

Welding Parameters: 50-50 Argon-Helium Shielding
300A

Electrode	Total Fume Generation Rate (g/min)	Cu Level in Fumes (%)	Welding Time to Critical Cu Fume Density (min)
Cuprotrode 521	1	25	0.8
Monel 451	0.85	45	0.5
Ampcotrode 10	0.256	79	1
Ampcotrode 46	0.619	82	0.4

Several inferences may be drawn from this Table. The Ampcotrode 10 is the most desirable electrode from a fume production standpoint whereas the Ampcotrode 46 displays the worst fume characteristics. Very short welding periods achieve critical Cu fume concentrations in the 10 m x 10 m x 10 m enclosure. Such limited periods would be extended through fume control measures to match power source duty cycles.

The local fume extraction unit evaluated here provided enhanced fume control. The gun-mounted local exhaust unit achieved a 35% fume collection efficiency. This compares favourably with the 27% calculated for the Tykron IV vacuum system as reported previously (22). Even so, toxic Cu and Ni fumes could necessitate higher collection efficiencies to maintain environmental fume levels within acceptable limits.

These could be achieved through greater emphasis on nozzle design, optimizing the location of the extraction tube on the welding torch and altering gas flow conditions. Higher gas flow velocities would increase shielding to allow positioning of the nozzle closer to the arc and the fume source. Improved fume extraction would result but higher gas costs would accrue. The actual efficiency can also be a function of the welding position. Overhead welding would be least efficient while welding in the flat position would optimize efficiency. The geometry demonstrates that welding with the plate positioned flat and the gun pointed vertically down would capture more rising fumes. Also additional nozzle adaptations could potentially improve the collection efficiency. Various hole configuration and airflow defectors would constitute worthwhile topics for further research.

Similar systems incorporated into high current automatic applications provide very economical exhaust systems since they exhaust much less air than general ventilation and reduce the contribution required from massive air makeup units to provide heated or cooled air to replace the air exhausted. It is quite easy to estimate the costs involved in operating a large mechanical ventilation system to remove the fumes from these experiments. For instance, a rough calculation in conjunction with Figure 20 would suggest that about 500 m3/min would have to be ventilated when relying exclusively on a general

exhaust system (Appendix A). The low volume airflow of an ancillary local exhaust system would thus be most cost effective.

5.0 Conclusions

1. Both the Ampcotrode 10 and the Ampcotrode 46 produce twice as much fume with 50% helium shielding than with only 15% helium mixed with argon.

2. While the Ampcotrode 10 exhibits monotonically increasing fume generation rates with increasing currents, the Ampcotrode 46 fume generation rate dips sharply for currents in excess of 300A with 50% helium shielding.

3. Both the Cuprotrode 521 and the Monel 451 used in the first study (23) tend to achieve at least 20% greater fume generation rates in a 50% helium shielding environment than the two electrodes evaluated in the present study.

4. Within the limits of experimental variation the electrodes of the previous (23) and present studies achieved similar fume generation rates with 100% argon and 85% argon shielding respectively.

5. Aside from possible ozone formation, the critical fume component was Cu for all electrodes.

6. In 50-50 argon-helium shielding at 300 A the electrodes from most toxic to least toxic fume emission are as follows:
1) Ampcotrode 46 2) Monel 451 (first report) 3) Cuprotrode 521 (first report) 4) Ampcotrode 10.

7. The Ampcotrode 10 produced minimum fume generation at 270A.

8. A gun-mounted local fume exhaust unit was investigated and found to be a potentially feasible means for controlling the fume emissions of Ni-Al-bronze electrodes.

6.0 Recommendations

1. Further experiments should be performed over a current range exceeding 300A to test both the Ampcotrode 10 and the Ampcotrode 46 electrodes. The dip in the fume generation rate of the Ampcotrode 46 could thereby be charted and an optimal low fume operating condition established. In addition the Ampcotrode 10 fume generation characteristic should be investigated for a similar dip at higher currents.

2. In all cases helium shielding evolved the greatest amount of harmful fumes. On the other hand helium shielding would be desirable for welding thick Ni-Al-bronze plate. In this trade-off a range of helium-argon proportions should be investigated to establish optimal mixtures compatible with both hygienic requirements and process demands.

3. Various design innovations should be tested on the local extraction unit with a view to increasing its fume collection efficiency.

4. The gun-mounted fume control unit should be tested on location for Ni-Al-bronze applications. A desirable test procedure would see fume concentrations monitored throughout the shop for the protection of ancillary personnel.

Acknowledgements

Thanks are due to Mr. N. Sweetman and Mr. D. Varo for their part in setting up the equipment involved in the investigation, and CANMET for technical discussions.

7.0 References

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2. ibid.

3. Canadian Standards Association Code for Safety in Welding and Cutting (Requirements for Welding Operators) W117.2, Rexdale, Ontario: CSA 1974, p. 39.

4. American Welding Society, Characterization of Arc Welding Fumes, Miami, 1979.

5. American Welding Society, Laboratory Test Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes, F1.2 - 79, Miami, AWS, 1979, p.2.

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7. ibid. p. 6.

8. ibid. p. 5.

9. ibid. p. 6.

10. Welding Institute of Canada Study of Welding Fume Characteristics of Copper-Nickel Alloy Gas Metal Arc Electrodes, p. 43 and 47.

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15. ibid. p. 86.

16. R. F. Helle and P. C. Hill, "Particulate Fume Generation in Arc Welding Processes", Welding Journal, July 1975, p. 209-s.

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18. American Welding Society, Characterization of Arc Welding Fumes, Miami, AWS, 1979, p. 92.

19. Welding Institute of Canada, Study of Welding Fume Characteristics of Copper-Nickel Gas Metal Arc Electrodes, Report RC141, Oakville, 1983, p. 40, 46.

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22. Study of Welding Fume Characteristics of Copper-Nickel Gas Metal Arc Electrodes, Report RC141, Oakville, 1983, p. 18.

23. Welding Institute of Canada Study of Welding Fume Characteristics of Copper-Nickel Alloy Gas Metal Arc Electrodes, p. 43, 47.

TABLE 1. Summary of Welding Conditions Used in GMAW Welds for Ampcotrode 10 and 46 Electrodes

Joint Design:	bead-on-plate
Electrode:	1.6 mm diameter Ampcotrode 10 for Al-Ni bronze base plate 1.6 mm diameter Ampcotrode 46 for Al-Ni bronze base plate
Shielding Gas:	85% argon + 15% helium mixture - 1.2 m^3/hr 50% argon + 50% helium mixture - 1.2 m^3/hr
Arc Voltage:	27 - 29 Volts
Current D.C. Electrode Positive:	270 - 330 Amps for both Ampcotrode 10 and Ampcotrode 46 electrodes
Travel Speed:	For 85% argon + 15% helium mixture (a) 5330 - 6350 mm/min for Ampcotrode 10 electrode (b) 5080 - 6730 mm/min for Ampcotrode 46 electrode For 50% argon + 50% helium Mixture (a) 5330 - 6480 mm/min for Ampcotrode 10 electrode (b) 5330 - 6480 mm/min for Ampcotrode 46 electrode

TABLE 2. Chemical Analysis (wt %) of Electrodes for Ni-Al-Bronze Alloys

	Mn	Si	Ni	Cu	Fe	Al
Ampcotrode 10	0.01	0.01	0.01	89.96	0.97	9.41
Ampcotrode 46	0.92	0.01	4.16	81.65	3.78	9.38

TABLE 3. Preliminary Calibration of Fume Generation

Procedure AWS F1.2-79
Wire: E70S-3 Steel 1.2 mm diameter
Plate: 12.5 mm thick steel plate
Gas: CO_2 at 19 litres/min

Tests (Volts)	Current (A)	Wire Speed (mm/min)	Fume Generation Rate (g/min)	% Deviation from AWS	Meets AWS (Yes/No)
26	190	7600	0.675	+27.3	No
26	180	7600	0.669	+26.2	No
26	180	7600	0.69	+30.19	No
26	225	7600	0.483	-8.86	Yes
26	225	7600	0.512	-3.40	Yes
24	180	7600	0.497	+15.6	No
24	195	7600	0.532	+23.7	No
24	225	7600	0.531	+23.5	No
24	190	7600	0.435	+1.16	Yes
24	190	7600	0.435	+1.16	Yes
24	190	7600	0.423	-1.16	Yes
24	180	7600	0.441	+2.56	Yes

TABLE 4. Fume Generation Rate During Bead-On-Plate Welds With Ampcotrode 10 Electrode and 85/15 Argon-Helium Mixture

Wire: Ni-Al bronze: 1.6 mm diameter
Plate: 25.4 mm thick Ni-Al bronze
Gas: 85% argon, 15% helium, 1.2 mm3/hr

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min)			FGR (mg/g of wire)
			Max	Min	Avg	
270	27	5330	0.213	0.198	0.206	4.30
300	27	5460	0.223	0.175	0.191	3.90
330	27	5330	0.394	0.300	0.349	7.28
270	29	5460	0.185	0.171	0.177	3.61
300	29	5900	0.316	0.226	0.262	5.34
330	29	6350	0.368	0.252	0.304	5.33

Average of 2 to 4 tests
Mean deviation from avg FGR $\pm$ 10%

TABLE 5. Fume Generation Rate During Bead-On-Plate Welds With Ampcotrode 10 Electrode and 50/50 Argon-Helium Mixture

Wire: Al-Ni bronze: 1.6 mm diameter
Plate: 25.4 mm thick Ni-Al bronze
Gas: 50% argon, 50% helium, 1.2 m^3/hr

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg	FGR (mg/g of wire)
270	27	5330	0.192	0.168	0.180	2.92
300	27	6100	0.268	0.244	0.256	4.67
330	27	6480	0.588	0.562	0.575	9.89
270	29	5490	0.153	0.152	0.153	3.11
300	29	5890	0.261	0.208	0.234	4.42
330	29	6480	0.440	0.356	0.398	6.85

Average of 2 tests
Mean deviation from avg FGR $\pm$ 6.1%

TABLE 6. Fume Generation Rate During Bead-On-Plate Welds With Ampcotrode 46 Electrode and 85/15 Argon-Helium Mixture

Wire: Ni-Al bronze: 1.6 mm diameter
Plate: 25.4 mm thick Ni-Al-bronze
Gas: 85% argon, 15% helium, 1.2 mm^3/hr

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg	FGR (mg/g of wire)
270	27	5080	0.397	0.244	0.302	6.62
300	27	5715	0.276	0.213	0.249	4.85
330	27	6730	0.232	0.228	0.229	3.79
270	29	5200	0.296	0.238	0.263	5.62
300	29	5590	0.375	0.268	0.307	6.12
330	29	6480	0.398	0.290	0.336	5.78

Average of 3 tests
Mean deviation from avg FGR $\pm$ 11.6%

TABLE 7. Fume Generation Rate During Bead-On-Plate Welds With Ampcotrode 46 Electrode and 50/50 Argon-Helium Mixture

Wire: Ni-Al bronze: 1.6 mm diameter
Plate: 25.4 mm thick Al-Ni bronze
Gas: 50% argon, 50% helium, 1.2 m^3/hr

Current (A)	Voltage (V)	Wire Speed (mm/min)	Fume Generation Rate (g/min) Max	Min	Avg	FGR (mg/g of wire)
270	27	5330	0.278	0.264	0.271	5.66
300	27	5590	0.640	0.598	0.619	12.34
330	27	6480	0.357	0.348	0.352	6.05
270	29	5330	0.320	0.312	0.316	6.6
300	29	5590	0.506	0.506	0.506	10.08
330	29	6480	0.612	0.474	0.543	9.34

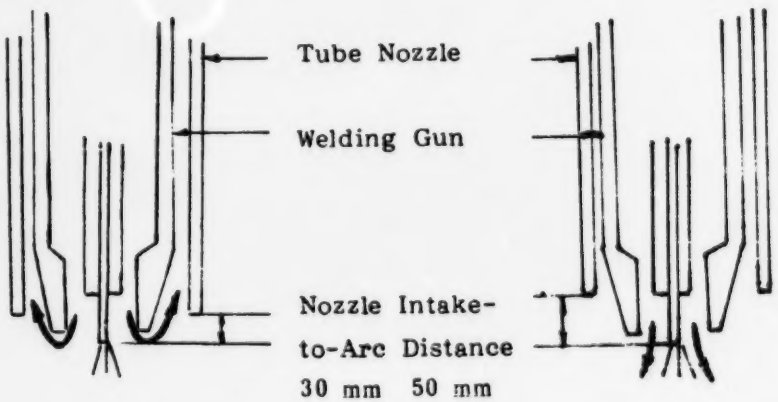
Average of 2 tests
Mean deviation from avg FGR $\pm$ 3.5%

TABLE 8. Data Sheet for Chemical Analysis

Electrode	Sample No	Fume Weight (g)	Welding Conditions Voltage (V)	Current (A)	Chemical Composition % Cu	Ni	Shielding Gas
Ampcotrode 10	1	0.0014	27	300	56	0.036	85-15 Ar-He
	2	0.0013	27	300	70	0.015	85-15 Ar-He
	3	0.0016	27	300	73	0.183	50-50 Ar-He
	4	0.001	27	300	84	0.42	50-50 Ar-He
	5	0.0011	27	270	65	0.09	85-15 Ar-He
	6	0.0010	27	270	61	0.05	85-15 Ar-He
Ampcotrode 46	7	0.0013	27	270	73	0.784	85-15 Ar-He
	8	0.0011	27	270	71	0.836	85-15 Ar-He
	9	0.0014	27	300	69	0.786	85-15 Ar-He
	10	0.0009	27	300	88	1.09	85-15 Ar-He
	11	0.0015	27	300	88	1.08	50-50 Ar-He
	12	0.0013	27	300	76	1.09	50-50 Ar-He
	13	0.0015	29	300	64	0.776	85-15 Ar-He
	14	0.0012	29	300	N/A	1.27	85-15 Ar-He

TABLE 9. Local Fume Extraction Tests

Test Conditions
Electrode - Ampcotrode 10
Shielding
Gas - 85%A + 15% HR
Current - 300A
Voltage - 27Volts
Weld
Time - 30 seconds
Wire Feed Rate
- 6730 mm/min



Nozzle Configuration	Nozzle Position	Fume Generation Rate With Local Exhaust	Fume Generation Rate Without Local Exhaust	Efficiency %	Comments
No holes	1	0.370	0.191	N/A	Shield gas removed
8 holes	2	0.159	0.191	16.8	Too much clean air exhausted
4 holes	2	0.129	0.191	32.5	Less clean air exhausted
8 holes with collar	2	0.123	0.191	35.6	Least clean air exhausted
No holes with funnel collector	2	0.212	0.191	N/A	Approx Zero Efficiency

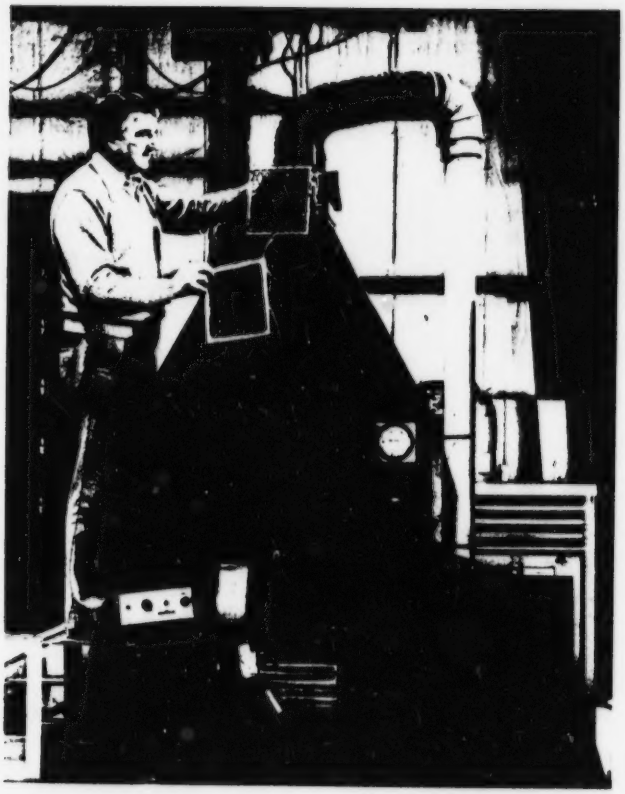


Figure 1. The welding fume chamber consists of a closed cabinet with filter element at its apex. A vacuum pump draws air from the chamber through the filter which retains particulate welding fumes.

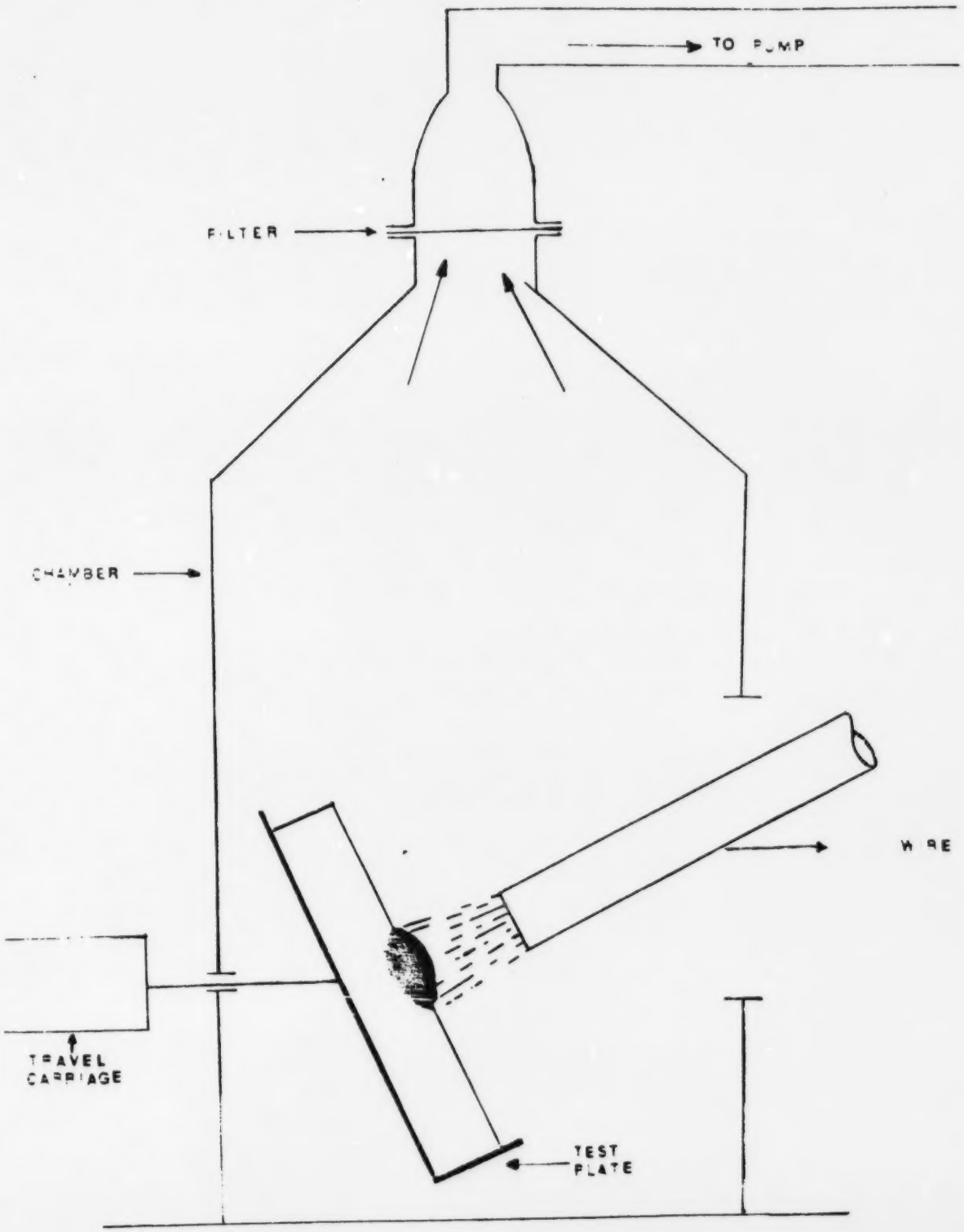


Figure 2. Schematic arrangement of test equipment.

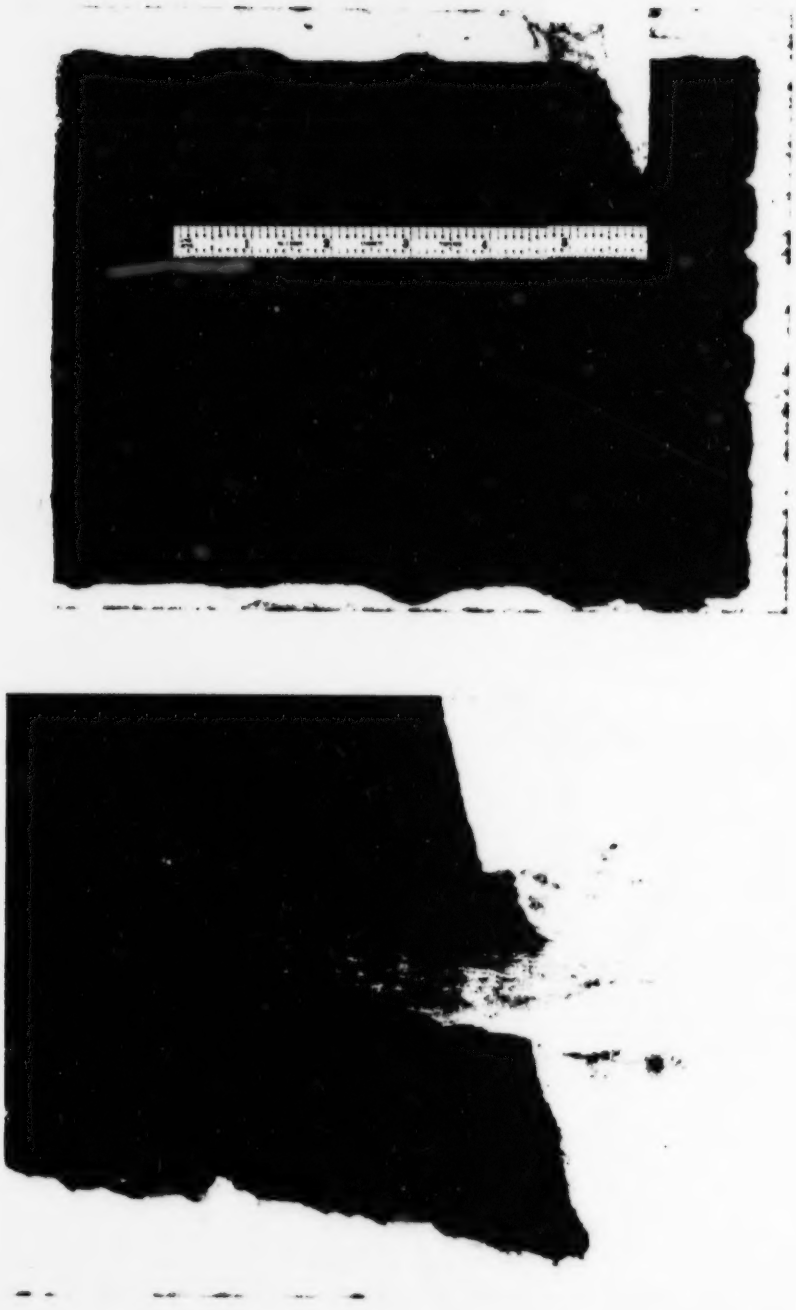


Figure 3. A typical fume deposit on the filter after a welding trial.

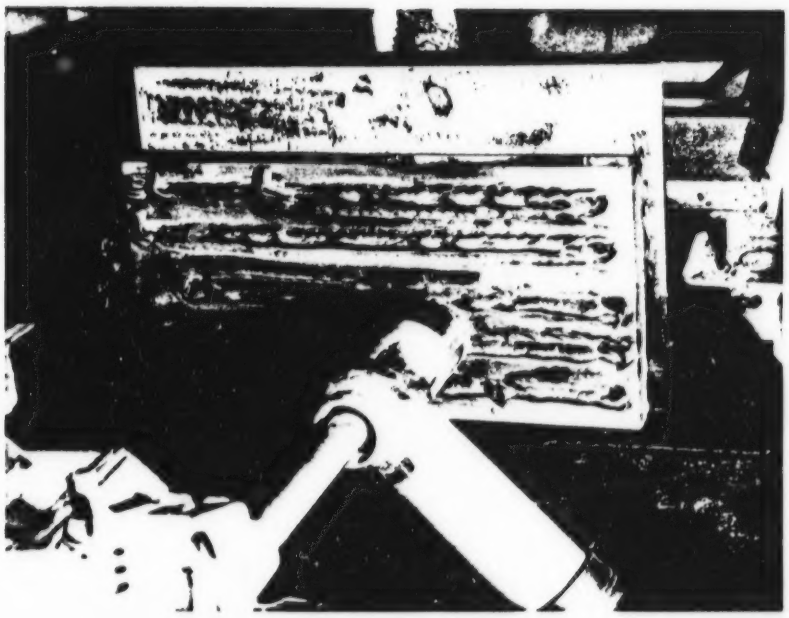


Figure 4. Gun-mounted tube nozzle with ring of 12 mm diameter holes above intake part.

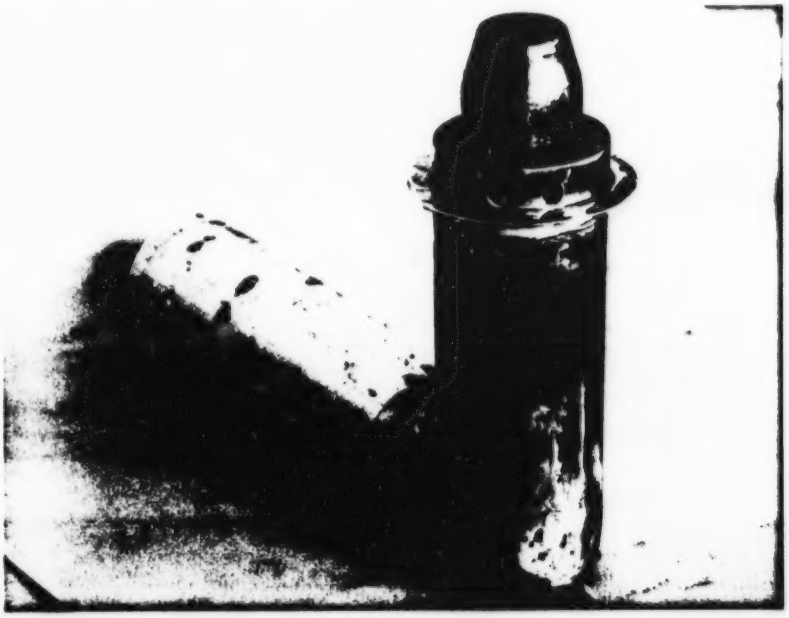


Figure 5. Close-up incorporating washer secured above small holes.

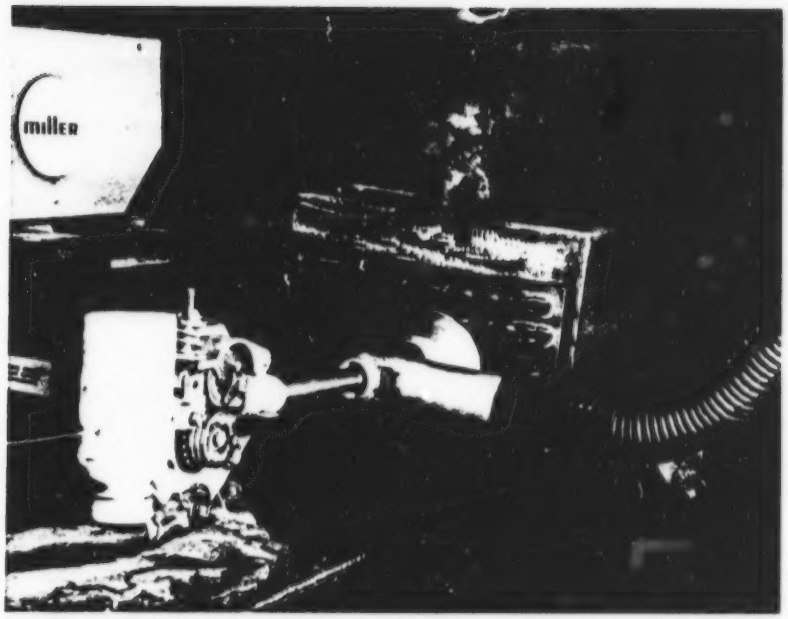


Figure 6. Gun-mounted tube nozzle incorporating funnel-shaped collector attached to intake port.

Figure 7. Close-up

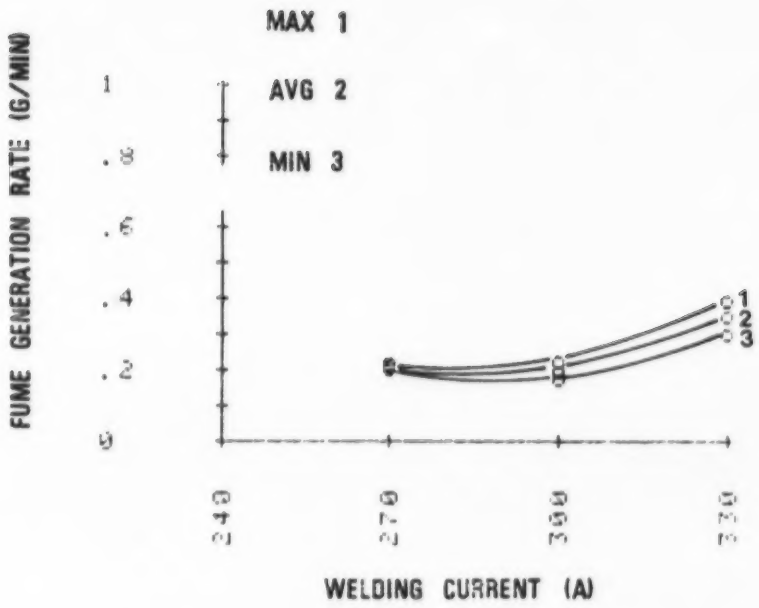


Figure 8. Fume generation rate during welding with Ampcotrode 10 electrode at 27 volts while using an 85-15 Argon-Helium shielding gas.

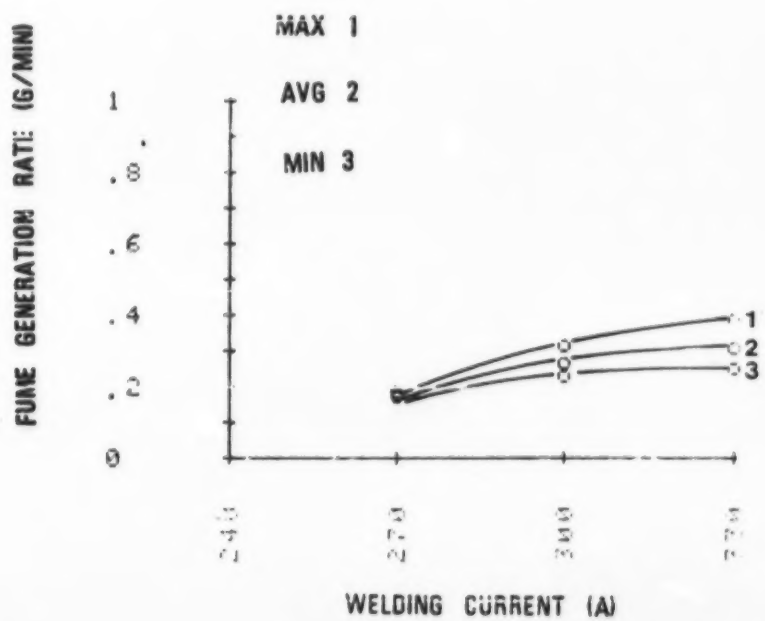


Figure 9. Fume generation rate during welding with Ampcotrode 10 electrode at 29 volts while using an 85-15 Argon-Helium shielding gas.

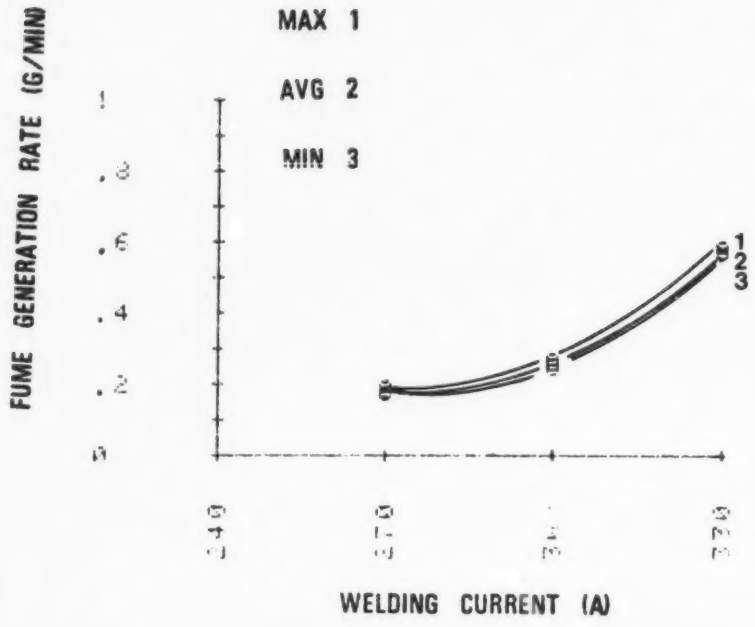


Figure 10. Fume generation rate during welding with Ampcotrode 10 electrode at 27 volts while using a 50-50 Argon-Helium shielding gas.

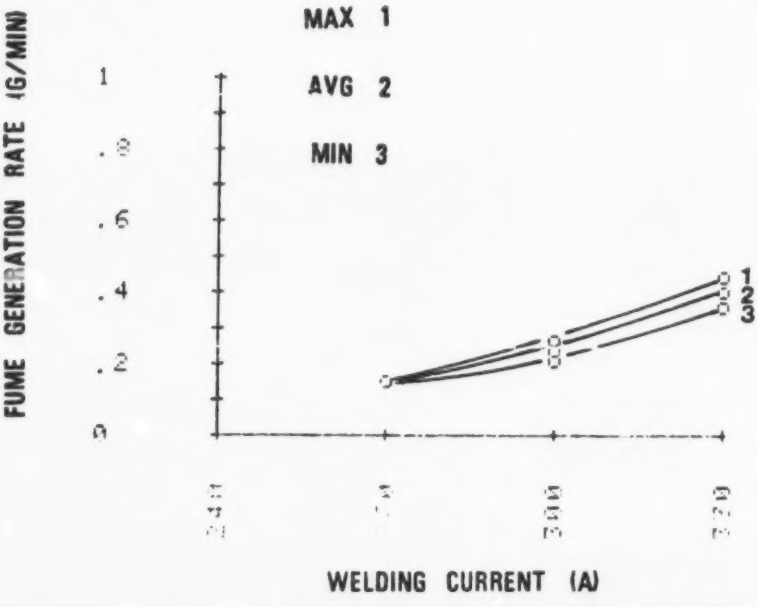


Figure 11. Fume generation rate during welding with Ampcotrode 10 electrode at 29 volts while using a 50-50 Argon-Helium shielding gas.

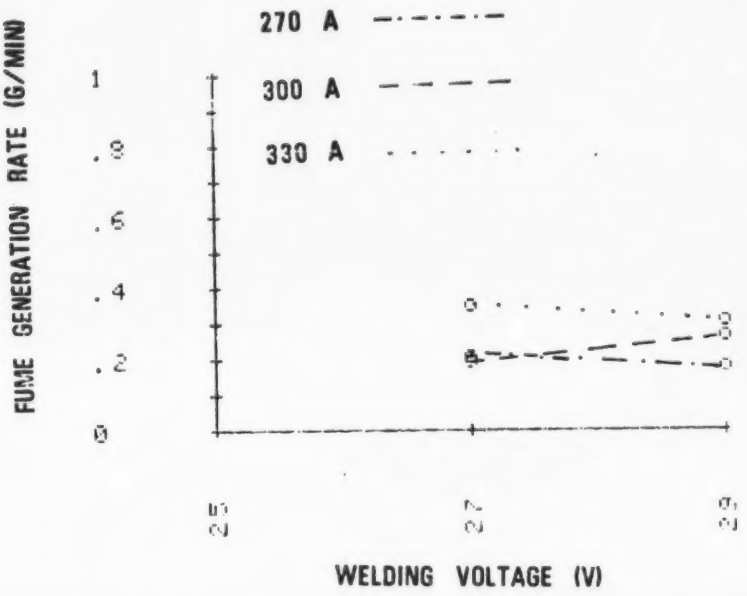


Figure 12. Average fume generation rate during welding with Ampcotrode 10 electrode at welding currents 270A, 300A and 330A with an 85-15 Argon-Helium shielding gas.

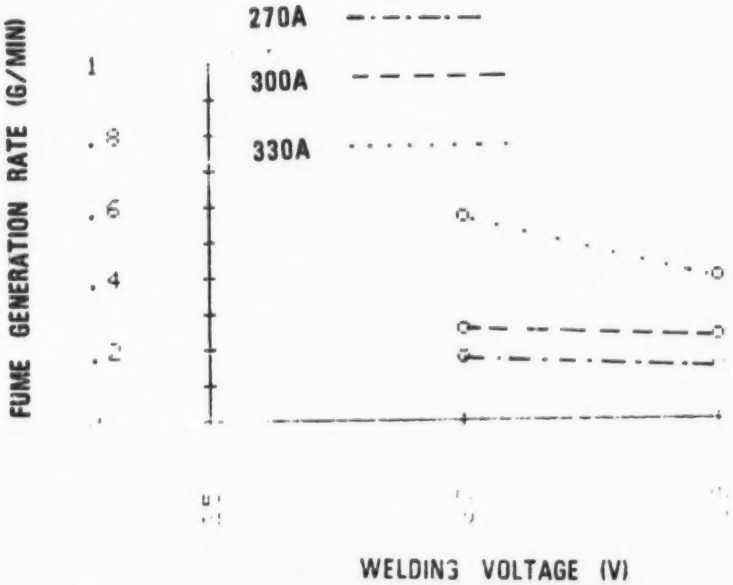


Figure 13. Average fume generation rate during welding with Ampcotrode 10 electrode at welding currents 270A, 300A and 330A with a 50-50 Argon-Helium shielding gas.

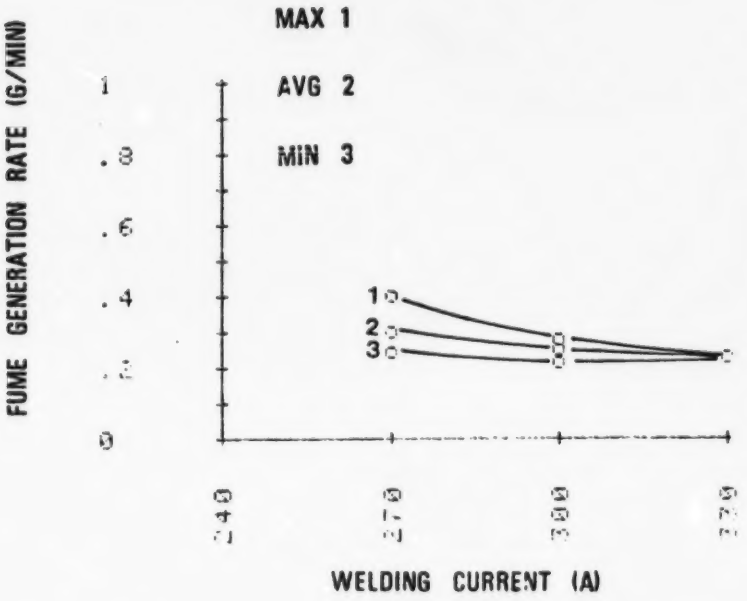


Figure 14. Average fume generation rate during welding with Ampcotrode 46 electrode at 27 volts while using 85-15 Argon-Helium shielding gas.

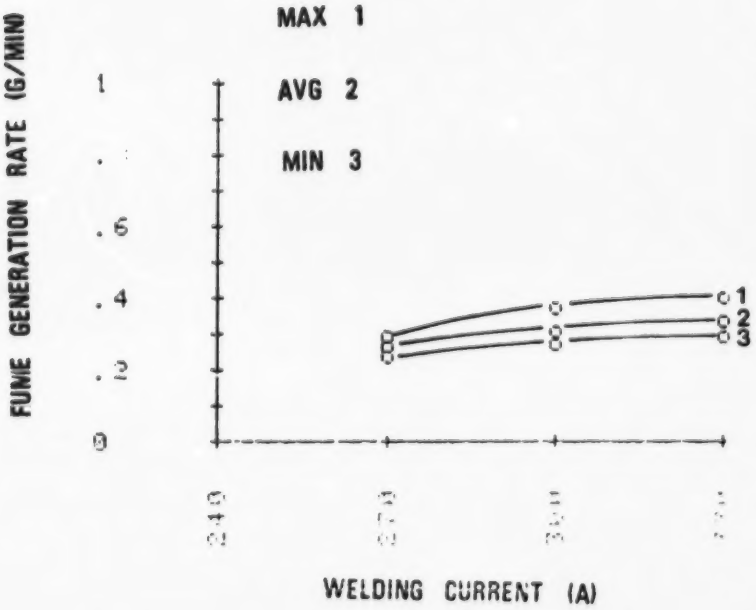


Figure 15. Average fume generation rate during welding with Ampcotrode 46 electrode at 29 volts while using a 85-15 Argon-Helium shielding gas.

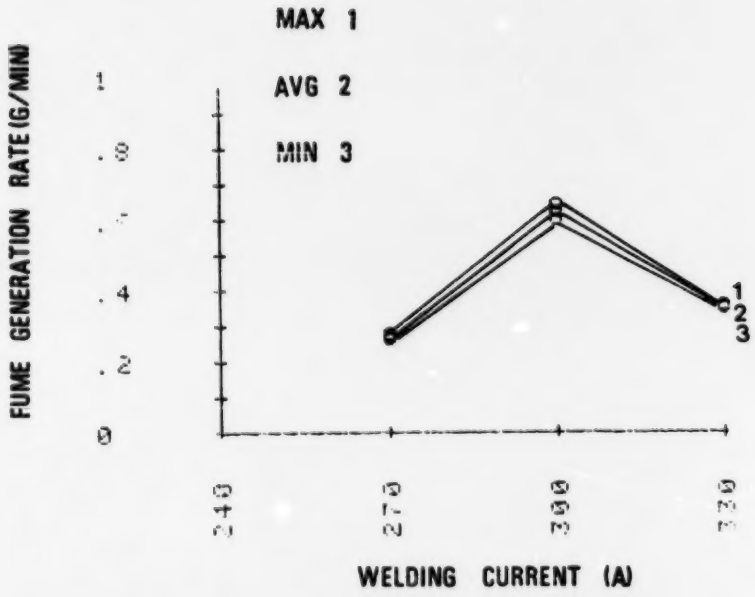


Figure 16. Average fume generation rate during welding with Ampcotrode 46 electrode at 27 volts while using 50-50 Argon-Helium shielding gas.

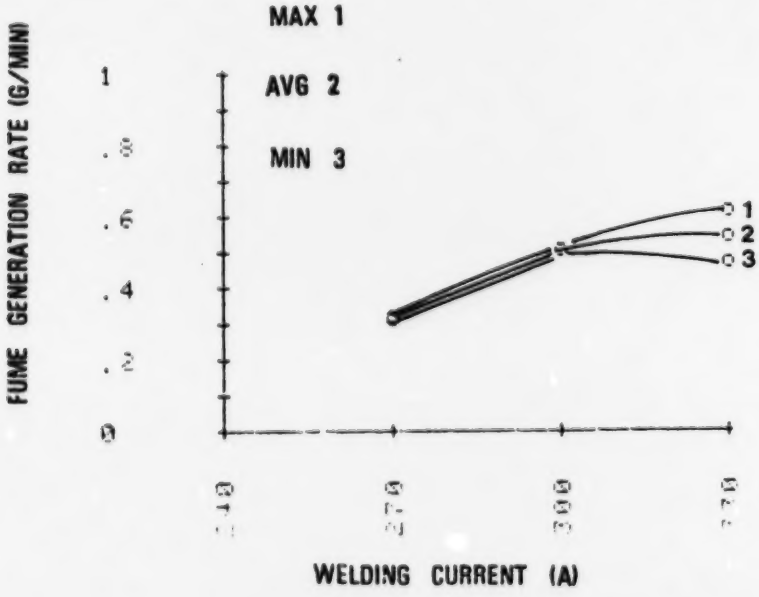


Figure 17. Average fume generation rate during welding with Ampcotrode 46 electrode at 29 volts while using a 50-50 Argon-Helium shielding gas.

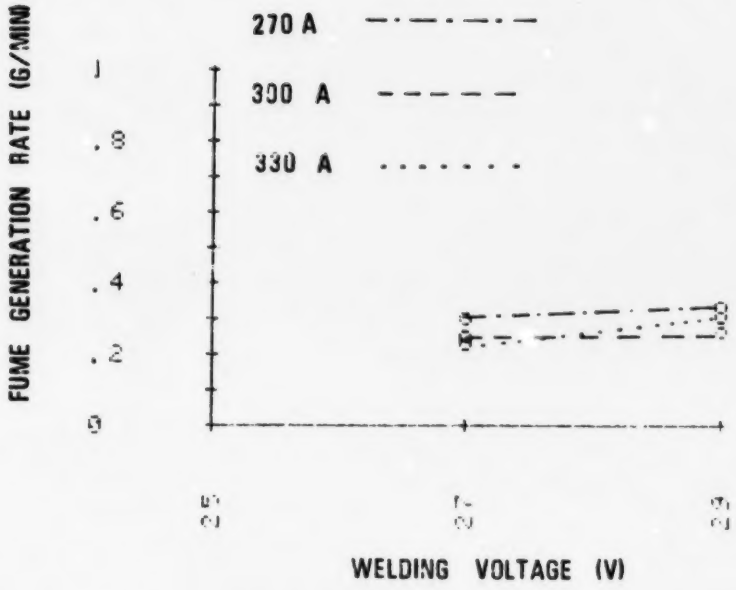


Figure 18. Average fume generation rate during welding with Ampcotrode 46 electrode at welding currents 270A, 300A and 330A with an 85-15 Argon-Helium shielding gas.

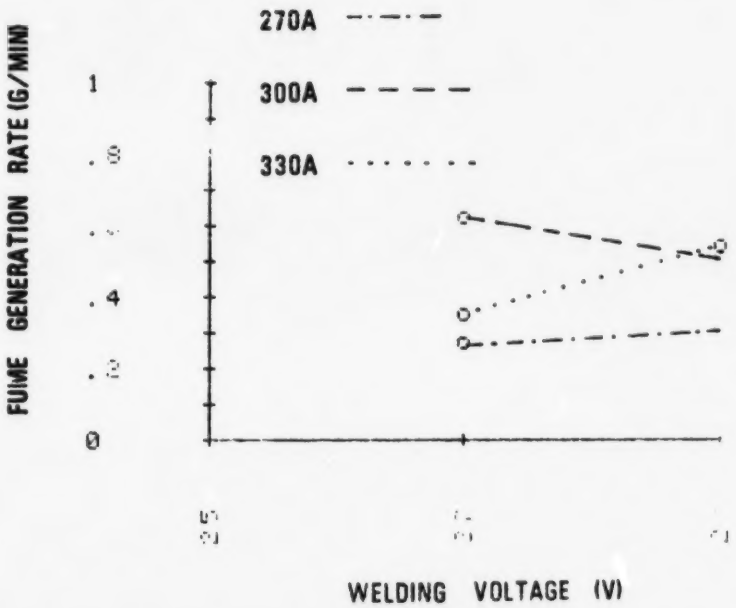


Figure 19. Average fume generation rate during welding with Ampcotrode 46 electrode at welding current 270A, 300A and 330A with a 50-50 Argon-Helium shielding gas.

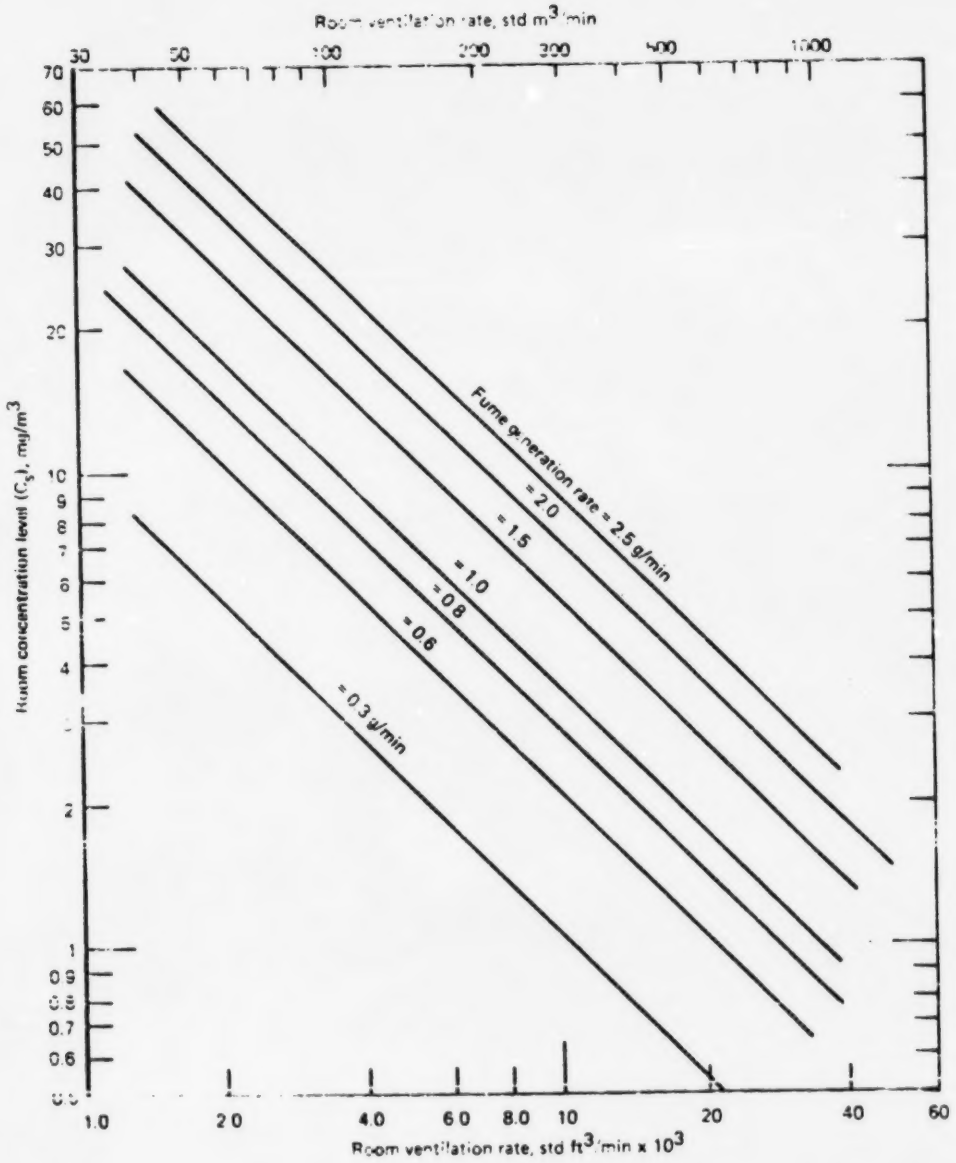


Figure 20. General room ventilation requirments for various welding fume generation rates (taken from reference 1 p.23).

APPENDIX A

APPENDIX A

Mechanical Ventilation Required When Using Ampcotrode 46 and Ampcotrode 10 Electrodes

1.	Threshold limit value of Cu is 0.2 mg/m3	(Part I)
2.	Cu is the critical fume constituent	(Part 2)
3.	Fume analysis records Cu fume percentage at about 30	(Table 8)
4.	Maximum allowable fume concentration is about 0.65 mg/m3	((1)/(3))
5.	Maximum anticipated fume generation rate is 0.6 g/min	(Fig 8-15)
6.	Ventilation requirement is about 500 m^3/min as read from chart	(Fig 20)

POOR

QUALITY

ORIGINAL